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Moose damage to pre-commercially thinned balsam fir stands: Review of research and management implications

Ian D. Thompson and William J. Curran

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by
Ian D. Thompson
and
William J. Curran

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Abstract

Moose *(Alces alces)* browsing damage has been observed in precommercially thinned stands of balsam fir *(Abies balsamea)* in Newfoundland. Damage ranged from more than 30% of the stems severely browsed and broken in some stands east of the Noel Paul River, to less than 1% damage in the Deer Lake area. Moose pellet groups, an indicator of moose density, was strongly related to browsing damage. Regression analyses indicated that the density of small balsam fir (3 m) influenced damage level and suggested that thinning of stands resulted in a superior feeding condition for moose.

Browsing patterns at a spacing trial near Harpoon Brook indicated that spacings wider than 1.2 m were more heavily used than the 1.2 m stands. However, although a similar trend was seen at a second site near Jeffrey's, results there were equivocal. The Jeffrey's results were confounded by relatively low browsing pressure and an excess of food throughout the area. We suspect that spacing is an important consideration in areas where there are high moose densities. Amount of deciduous browse present in the stand did not influence damage to balsam fir. At the spacing trials, there was no effect of distance from an uncut edge on amount of browsing damage. However, during the stand surveys, we observed that pockets of thinned balsam fir surrounded by uncut forest were severely browsed.

Twigs from balsam fir in thinned stands were more digestible, longer, heavier, had a greater diameter, and contained higher levels of protein and some macroelements than twigs from unthinned balsam fir. Secondary compound concentrations apparently did not influence choice of stand as concentrations were highest in trees from thinned stands, opposite to the direction predicted. Protein levels from unthinned fir were below winter maintenance requirements of moose. We suggest that moose feed preferentially on trees in thinned stands because of greater biomass per tree and higher protein levels available compared to unthinned stands.

Thinning of stands could be conducted in a manner that would make stands somewhat less attractive to moose. We recommend increased density of older, taller trees, and removal of uncut timber. We recommend that a decision as to resource priority be made prior to extensive thinning operations. If land managers decide that timber is a priority resource for a given area, then moose density must be reduced to probably less than 1 moose/km^2. Moose should be maintained at that level until average height in the thinned stands is tall enough that trees cannot be broken by moose (4-5 m). If the decision is made that production of wildlife which requires young stands of timber is the priority, then thinning of forests should not be undertaken.

Résumé

On a observé que le broutage des orignaux *(Alces alces)* avait causé des dommages à des peuplements de sapins baumiers *(Abies balsamea)* de Terre-Neuve où des éclaircies précommerciales avaient été pratiquées. Plus de 30% des tiges étaient gravement broutées et brisées dans certains peuplements à l'est de la rivière Noel Paul; des dégâts mineurs ont aussi été relevés dans la zone de Deer Lake. Des tas de crottin d'orignal, un indicateur de la densité de ces animaux, ont été formellement reliés aux dommages causés par le broutage. Des analyses de régression indiquent que la densité de petits sapins (- de 3 m) a une influence sur la gravité des dommages et laissent supposer que les éclaircies pratiquées dans les peuplements créent pour l'orignal de meilleures conditions de broutage.

Lors d'un essai d'espacement mené au ruisseau Harpoon, les modes de broutage révèlent que les peuplements espacés de plus de 1, 2 m sont plus gravement affectés que ceux espacés de 1, 2 m ou moins. Toutefois, même si une tendance similaire a été observée dans une autre station, près de Jeffrey's, ces derniers résultats semblent équivoques: en effet, des différences reliées au niveau peu élevé de broutage et à l'excès de nourriture dans la région nous rendent perplexes. Nous avons lieu de penser que l'espacement joue un rôle important dans les régions où la densité des orignaux est élevée. La quantité de broutilles feuillues présente dans le peuplement n'a pas influencé les dommages causés aux sapins baumiers. Dans les parcelles d'essai d'espacement, la distance de la lisière non éclaircie n'avait aucun effet sur l'importance des dégâts causés par le broutage. Cependant, au cours des relevés, nous avons observé que des îlots de sapins baumiers éclaircis entourés de secteurs non exploités étaient fortement broutés.

Les rameaux de sapins des peuplements éclaircis étaient plus faciles à digérer, plus longs, plus lourds et d'un plus fort diamètre que ceux des sapins poussant dans des peuplements non éclaircis, et contenaient des niveaux plus élevés de protéïnes et de certains macroéléments. Les concentrations en composés secondaires n'ont apparemment eu aucune incidence sur le choix des peuplements étant donné que ces concentrations étaient plus élevées dans les arbres des peuplements éclaircis, contrairement à ce qui avait été prévu. Les niveaux de protéïnes des sapins des peuplements non éclaircis sont inférieurs aux besoins de nutrition des orignaux en hiver. Nous croyons que les orignaux préfèrent se nourrir dans les peuplements éclaircis parce qu'ils offrent plus de biomasse par arbre et des niveaux de protéïnes plus élevés que les peuplements non éclaircis.

Les éclaircies devraient être pratiquées de façon à rendre les peuplements moins attirants pour les orignaux. Nous recommandons une plus grande densité d'arbres plus âgés et plus grands, et l'élimination des billes non débitées. Nous recommandons également qu'avant de mener des opérations d'éclaircie de grande envergure, une décision soit prise quant aux ressources auxquelles on désire accorder la priorité. Si les gestionnaires des terres décident que l'exploitation forestière est prioritaire pour une région donnée, ils devront probablement ramener la densité d'orignaux à moins d'un par kilomètre carré; ce niveau de population devrait être maintenu jusqu'à ce que les arbres dans les peuplements éclaircis aient atteint une hauteur moyenne de 4 à 5 m, hauteur à partir de laquelle les orignaux ne peuvent les briser. Par ailleurs, les éclaircies seront à proscrire si la priorité est accordée aux espèces fauniques qui exigent de jeunes peuplements.

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Introduction

A major component of second (and third) growth forest in Newfoundland is balsam fir *(Abies balsamea).* Homogeneous stands of balsam fir and mixed stands of fir/white spruce *(Picea glauca)*/black spruce *(P. mariana)* grow in extremely dense stands after logging of balsam fir and fir/spruce sites. Unthinned stands average about 30,000 stems/ha and range as high as 80,000 stems/ha (M. Lavigne, For. Can., pers. comm., Thompson 1988). At about 10 or more years after logging, such sites may be thinned to increase the growth rate of the remaining trees (Baskerville 1965, Piene 1981, Lavigne and Donnelly 1989). At present about 30,000 ha of forest on the island have been thinned. Thinning results in more or less evenly spaced trees approximately 2.2 m apart at a density of 2000 stems/ha. Some preliminary observations by foresters suggested that moose were damaging trees by browsing in pre-commercially thinned areas.

Moose Populations

Moose populations in Newfoundland have achieved exceptionally high levels for a North American herd. Densities are from 1 to > 3 moose/km² in the island portion of the province (S. Oosenbrug, Nfld. Wildlife Div., pers. comm.). Balsam fir is a principal forage species (Petrides 1975) from fall through winter (Thompson, unpub. data). At high densities ungulates can influence vegetation growth, and habitat damage by moose in several areas of Newfoundland was previously reported by Pimlott (1963) and Bergerud and Manuel (1968). In the latter case, an attempt was made to reduce browsing on regenerating forest trees through a moose population reduction in the Noel Paul drainage basin in 1960-61 (Bergerud *et al.* 1968). They found that substantially less damage to balsam fir trees occurred up to four years later, but the herd was allowed to increase and long-term results were not measured.

In Sweden, dense populations of moose have resulted in habitat damage analogous to our problem, through browsing of second growth Scots pine *(Pinus sylvestris)* forests and plantations (Lavsund 1981). Swedish managers have attempted to lower their moose population as a means of reducing forest damage. The program has been successful in some areas, but not in others owing to extremely high numbers of moose and migratory herds.

Study objectives

The study involved several aspects, some of which have been reported in Thompson (1988) and Thompson *et al.* (1989). However, results from all aspects of the study and previously unpublished data will be summarized here. The objectives of the research were: 1) to determine the level of damage to thinned sites in several areas of the province, 2) to determine factors attracting moose to thinned stands, and 3) to provide guidelines for management to reduce moose browsing damage in pre-commercially thinned stands of balsam fir.

Study Area and Methods

The forests of Newfoundland are boreal and the principal tree species are balsam fir and black spruce (Damman 1983). Climate has a strong maritime influence and is characterized by almost constant winds, annual precipitation of 100-125 cm with a snowfall of about 300 cm, and temperatures ranging from a February average minimum of -10° C to a July average maximum of 20° C (Banfield 1983).

1) Stand survey

During the summer of 1986, 21 thinned stands and 16 adjacent unthinned stands located in the western and central areas of Newfoundland were surveyed for browsing damage by moose (Figure 1). Sites were chosen based on the criterion that thinning had occurred during the fall of 1983 or the spring of 1984, so that two years of growth had occurred. All sites were accessible by vehicle or all-terrain cycle.

Stands were surveyed for stem density and damage by moose using a plotless method (Batcheler 1975). This method involves placing a number of points within a stand and measuring three distances from point to plant, and from plant to plant. The method is described more fully in Thompson (1988).

Two height classes of trees were censused at each point: 0.5 to 2.9 m, and > 3.0 m, because moose can browse the tops of trees less than 3 m tall. Species, height, and level of browsing damage was recorded for each tree in both height classes. Three browsing damage classes were recognized: no

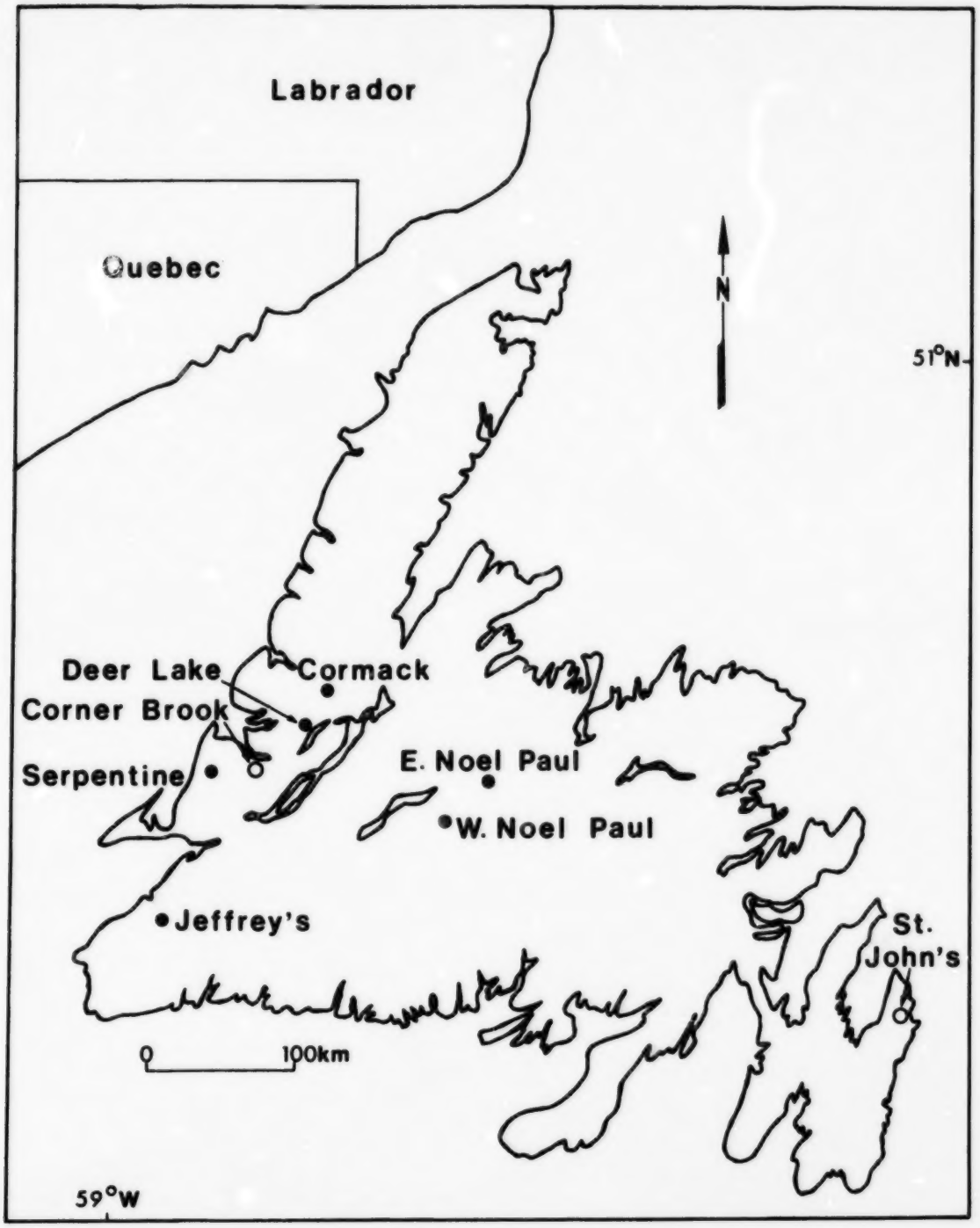

Figure 1. Locations of stands surveyed for browsing damage by moose in Newfoundland, 1986.

damage, light browsing - less than 50% of the current annual growth removed, and severe browsing - more than 50 percent of the current annual growth removed, or trees where the stem had been broken. Moose winter pellet groups were counted on 20 randomly placed 10m² circular plots as an indirect estimate of time spent by moose in each stand (Neff 1968). During our survey we made qualitative observations of how the damage was distributed within each stand, and made particular note of proximity of edges.

T-tests were used to examine differences in vegetation variables and pellet density between thinned and unthinned stands (Sokal and Rohlf 1981). Stepwise multiple linear regression (Draper and Smith 1966), with correlated variables removed, was used to examine the percentage of stems browsed in all stands using the following variables: density of pellet groups per plot, density/m² of balsam fir, black spruce, white spruce, deciduous shrub species combined, average height (m) of the stand, average height of residual black spruce, density of balsam fir under 3 m, percent of the stems under 3 m that was balsam fir, and the average height under 3 m. The analysis was run a second time omitting moose pellet group density in order to assess effects of vegetation variables. The same pair of analyses was run among thinned stands alone to determine if there were some common factors which influenced the level of damage by moose without the influence of the over-riding difference in balsam fir density between thinned and unthinned stands.

2) Spacing trials

Forestry Canada has two spacing trials designed to study the effects of inter-tree distance on growth rates of balsam fir. We examined the two sites for moose browsing to determine if the different spacings affected the rate of damage. The design of the two spacing trials was the same: 0.25 ha plot size, spacings of 1.2, 1.8, 2.4, and 3.0 m, with three replicates of each spacing. Both trial areas were established in spring of 1986, damage occurred during the winter of 1987, and we surveyed the plots in spring 1988. One of the 2.4 m plots was fertilized with urea in 1987. We analyzed results from that plot separately and report differences where they were significant. The hypothesis that we tested was: as a stand is opened the twig quality to a feeding moose likely increases to some upper asymptote; conversely, as the tree density decreases the value of the stand as cover or security to a feeding moose declines to a lower asymptote. We suggested that there would be an optimum where these two curves intersected (Figure 2).

All spacing plots and adjacent unthinned controls were subdivided into 5 x 5 m subplots, and 20-25 of the subplots (depending on anticipated variance) were randomly chosen for sampling. Measurements were taken on all trees within a plot as described above and number of stems browsed and total stems were recorded for each subplot. Data were analyzed by nested ANOVA to test for among spacing, and among plot (i.e., within spacing) differences in browsing damage under the null hypothesis that damage would be uniform among plots and spacings. We attempted to assess whether distance to an uncut edge or residual tall stand affected rate of browsing by measuring the difference from each subplot to uncut timber. The distance data and browsing rates were examined by correlation analysis separately and combined for the two sites.

In order to determine if two or more variables were interacting to affect moose browsing on the subplots, we analyzed deciduous stem density, distance to uncut edge, density of balsam fir 1 m, and density of tall balsam fir (=spacing) by stepwise

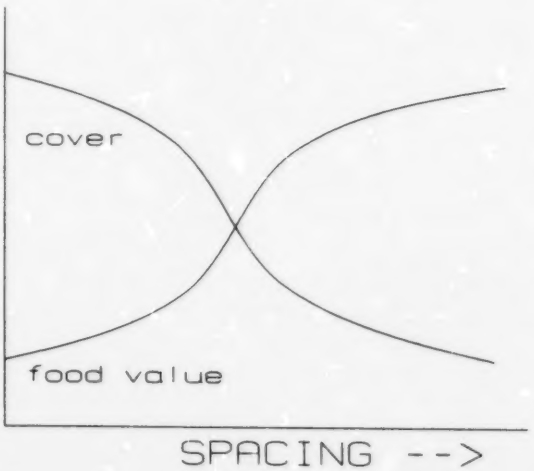

Figure 2. Null hypothesis for the spacing trial experiment: asymptotic value of a spaced stand to moose with some unknown spacing which optimizes food value of the food provided by trees and the cover to a browsing moose within the stand.

regression analysis with the number of balsam fir stems over 1 m that were browsed as the dependent variable. Tolerance was set to 0.15 and none of the variables used in the regression was correlated.

3) Physical and chemical analyses of balsam fir twigs

One stand, near Buchans, with two years of growth since spacing in 1986, was examined for differences in the nutritional quality to moose of the twigs produced by trees within the thinned stand and from trees in an adjacent unthinned area. We tested the null hypothesis that twigs from the two stands were of equivalent value as food to moose.

We collected all current annual growth of foliage and twigs between 1 and 3 m above-ground from 40 balsam fir trees in the thinned stand and randomly from 40 trees in an adjacent unthinned stand. Moose were browsing in the thinned stand at the time the collection was made on January 12, 1988 and so we were able to select trees already lightly browsed (majority of lateral and crown twigs remaining). Trees which were obviously chlorotic were not chosen for testing, because Bergerud and Manuel (1968) found that such trees were not browsed by moose.

We measured length, basal diameter, and wet weight of the ten longest twigs from each tree sampled. These twigs and enough of the remaining twigs to make up a sufficient sample for nutrient analyses (50g dry weight) were then oven-dried at 70°C until no more weight loss was observed (approximately 24 hours). Dry weights were determined for the ten twigs from each tree and all dry twigs were ground in a Wiley mill using a number 20 sieve.

Duplicate subsamples of twigs from each tree were analyzed for neutral detergent fiber (NDF), acid detergent fiber (ADF) (Van Soest and Wine 1967), N content by microkjeldahl analysis, percent ash (AOAC 1970), crude fat content (primarily resins, [Bryant and Kuropat 1980]) by heated ether extraction, macronutrients (P, K, Ca, Mg, and Na) by atomic absorption spectrophotometry (Black 1965), and *in vitro* dry matter digestibility (DMD) using the method of Tilley and Terry (1963). The latter analysis and the fiber analyses were done by Dr. R. McQueen at the Agriculture Canada Animal Research Laboratory, Fredericton.

Twigs used for secondary compound analyses were kept frozen in sealed plastic bags and shipped packed in dry ice one week after collection, where they were stored at -20°C for three months. Gas chromatography was conducted on foliage from four twigs chosen randomly from 20 trees in each of thinned and unthinned samples. Each subsample of plant material (ca. 200 mg) was soaked in 5.0 ml of a solution of dichloromethane containing 0.1068 mg/ml of 4-heptanone (internal standard) for 2 days at 27°C. Details of the analysis is in Thompson *et al.* Analyses for volatile metabolites were done by Dr. P. Reichardt, University of Alaska Chemistry Department, Fairbanks.

To obtain an estimate of food available per hectare in the two types of stand, we used data on current annual growth of foliage of balsam fir in thinned and unthinned stands in Newfoundland from Lavigne (1985). We then converted this to an estimate of total annual browse biomass production using the ratio of leaf weight to twig weight determined from our twig collection.

Comparisons between thinned and unthinned trees were done by *t-tests*. We conducted correlation analyses among all variables to determine those to be used in regression analysis. We then analyzed the relationship between DMD and uncorrelated nutrient content variables using simple linear regression and multiple regression analyses. Significant differences were accepted if $P < 0.05$.

Results

1) Damage to thinned balsam fir stands

Level of damage to thinned stands of balsam fir varied in different areas of the province (Table 1). Stands in the Noel Paul Brook drainage area and near Cormack were most heavily browsed, while least browsed stands were located in the Serpentine area, south of Corner Brook and near Deer Lake. Severe damage to more than 20 percent of the fir stems taller than 0.5 m occurred on five of the 21 thinned sites surveyed. Percentage of stems browsed in unthinned stands was substantially less than in thinned stands and severe damage occurred to less than 2 percent of the trees in all cases. No damage was found to nine of 16 unthinned stands surveyed (Table 1). On average, 321 stems/ha were severely damaged in thinned stands (both height classes combined) compared to 79 stems/ha in unthinned sites.

Structure and species composition of stands

Table 1. Moose damage to thinned and unthinned balsam fir stands in Newfoundland. Light damage refers to less than 50% of the current annual growth removed and severe damage to more than 50% of the current annual growth removed and/or the stem broken.

		Mean percent of balsam fir stems browsed by height class					
		3.0-6.0 m			0.5-2.9m		
Site	N	Light	Heavy	Range heavy	Light	Heavy	Range heavy
Unthinned:							
W. Noel Paul	5	2.6	0.2	0-0.8	2.8	0.5	0-1.9
E. Noel Paul	3	0.4	0	0	2.4	0.2	0-0.8
Cormack	1	0	0	0	1.2	0.6	
Deer Lake	3	1.3	0	0	2.9	0	
Serpentine	2	0	0	0	2.6	0	
Jeffrey's	1	0	0	0	0	0.7	
Thinned:							
W. Noel Paul	5	42.6	10.0	0.7-17.9	22.2	18.4	2.4-29.7
E. Noel Paul	2	30.5	2.6	0- 3.8	23.3	9.9	7.2-11.9
Cormack	2	34.6	9.9	3.7-15.4	19.8	23.8	19.9-31.2
Deer Lake	6	10.3	3.3	0.5-11.6	7.0	8.9	0.7-22.1
Serpentine	3	7.4	2.3	1.1- 4.2	6.7	4.2	2.6- 5.4
Jeffrey's	3	14.9	4.4	1.1- 9.7	10.9	6.3	1.5-13.6

changed as a result of thinning. The obvious change was in density of conifers, but thinned stands also contained a higher percentage of deciduous shrub species, and a lower density of deciduous trees (mostly white birch) over 3 m ($P < 0.01$) in all cases). Density of moose pellet groups was higher in thinned compared to unthinned stands ($P < 0.001$) (Table 2).

Amounts of light and heavy damage in individual stands were correlated ($r_S = 0.64$, $P = 0.002$). Light damage was more common and less variable than heavy damage but because important predicator variables were sometimes different, results for both damage classes are given (Table 3).

Moose pellet group density was the most important variable influencing increased browsing damage as suggested by three of four regressions where pellets were included (Table 3, columns 1 and 3). However, the percent of stems heavily damaged increased with the lower density of balsam fir trees under 3 m in thinned compared to unthinned stands, while moose pellet groups accounted for only 7% of the variance (Table 3, column 1).

When unthinned stands were deleted from calculations, moose pellet groups was the most important variable explaining damage within thinned stands (Table 3, column 3), clearly indicating that damage is a function of moose density. There was a significant linear regression between severe browsing damage and pellet group count (= moose density):

$$\text{Damage density} = 0.49 + 5.58 \text{ (pellet count)}$$
$$F = 74.8,\ P = 0.001,\ r^2 = 0.70).$$

From a forest management perspective, the fact that increased time by moose (or density of moose) in a stand results in higher damage suggests nothing about whether some habitat features might attract moose to certain stands more than to others. Regressions which included only vegetation variables (Table 3, columns 2 and 4) generally indicated that the density of small balsam fir (< 3 m) and the percent of stems of all species that was small

Table 2. Summary statistics for variables characterizing browsing rates by moose in thinned and unthinned stands and used in regression and principle components analyses.

Variable	Unthinned		Thinned	
	$\bar{x}$	*SD*	$\bar{x}$	*SD*
Density Fb > 3m[a]/m²	0.224	0.153	0.042	0.013
Density Sb > 3m /m²	0.018	0.020	0.005	0.006
Density Sw > 3m /m²	0.010	0.021	0.003	0.003
Density decid. spp. > 3m /m²	0.014	0.029	0.001	0.002
Mean Ht > 3m (m)	3.54	0.32	3.66	0.29
Ht Sb > 3m (m)	3.82	0.47	3.91	0.32
Density Fb < 3m /m²	1.83	0.78	0.211	0.114
% Fb < 3m	87.30	10.35	56.35	21.29
Density decid. spp. < 3m /m²	0.209	0.203	0.239	0.266
% decid. < 3m	11.57	9.79	40.09	22.10
Mean ht < 3m (m)	1.53	0.14	1.42	0.18
Pellet groups/10m²	0.07	0.13	0.47	0.43

[a] < 3m or > 3m refers to height class; Fb = balsam fir *(Abies balsamea)*, Sb = black spruce *(Picea mariana)*, Sw = white spruce *(Picea glauca)*; Decid. = all deciduous species (primarily *Betula papyrifera)*.

Table 3. Summary of stepwise multiple regression analyses for the dependent variable of moose browsing on balsam fir trees in thinned and unthinned stands in Newfoundland. (Significant variables reported.)

Damage Class	Stand type comparisons			
	Thin/unthin (pellet[a] included)	Thin/unthin (pellet excluded)	Thin only (pellet included)	Thin only (pellet excluded)
Light r^2	0.81	0.52	0.81	0.62
P	<0.001	<0.01	<0.001	<0.001
Partial r^2	Pellet = 0.70 Fbsh[b] = 0.08 %Fbsh = 0.03	Fbsh = 0.40 Sb3 + = 0.06 %Fbsh = 0.06	Pellet = 0.66 %Fbsh = 0.07 Sb3 + = 0.06	Sb3 + = 0.29 %Fbsh = 0.24 Fbsh = 0.09
Heavy r^2	0.93	0.82	0.71	0.18
P	<0.001	<0.001	<0.001	<0.05
Partial R^2	Fbsh = 0.86 Pellet = 0.07	Fbsh = 0.82	Pellet = 0.71	%Fbsh = 0.18

[a] Pellet = pellet group density /10 m² plot.

[b] Fbsh = density of balsam fir/m² *(Abies balsamea)* < 3m; %Fbsh = % of all stems < 3m that were balsam fir; Sb3 + = density of black spruce/m² *(Picea mariana)* > 3m.

balsam fir were two important variables influencing the amount of browsing by moose.

The density of tall black spruce accounted for 29 percent of the variance for thinned sites alone in the light damage regressions. Principal components analysis was used as a check of the importance of black spruce as a variable in the system (Green 1979). Of the twelve variables in the analysis (Table 2), black spruce density ranked sixth suggesting minor importance (most important variables were density of small balsam fir and density of tall balsam fir). A review of the data showed that on three of the most heavily browsed sites there was a high density of spruce and this probably accounted for the regression result.

Qualitative observations indicated three situations which enhanced browsing damage: pockets of thinned fir surrounded on three sides by uncut timber, thinned fir close to the top of a ridge of uncut timber, and thinned stands which contained islands of uncut timber.

2) Moose browsing in spacing trials

Moose density from pellet plot counts showed that the population (or time spent on the plots) was substantially higher at Harpoon compared to Jeffrey's ($P < 0.0001$). Our observations of moose also suggested a high population at Harpoon, and this site has previously been reported as a high moose density area (Bergerud and Manuel 1968).

Species composition at the two study sites differed: there was a larger black spruce component for all spacings at Harpoon (range for 1-3 m height: 2.2-6.4%) compared to Jeffrey's (range 0-1.1%); and more deciduous trees and shrubs occurred at Jeffrey's (range for 1-3 m plants: 32.2-72.8) than at Harpoon (range: 8.7-21.1%) (Table 4). Damage from moose browsing was heaviest at the Harpoon study area with greater than 50% of the stems heavily browsed and more than 39% of the stems broken, for some spacings (Table 5). The trend to not browse in unthinned areas observed during the stand survey portion of the study, was seen again at both sites (Figures 3 and 4).

Number of balsam fir stems browsed was not correlated with distance to uncut edges or residual stands at either site ($r = -0.09$, $P = 0.67$). The amount of deciduous browse plants available also did not affect damage to balsam fir for any of the spacings at either site (Table 6). We observed three significant correlations between the density of available deciduous browse stems and the number of balsam fir stems browsed. In one case the correlation was negative, but in all three cases the coefficient value was low, suggesting a sample size effect. Correlations at the fertilized plot did not differ from the values observed at the other plots spaced at 2.4 m.

For individual plots at Jeffrey's, the fertilized plot had the most deciduous stems of all plots ($F = 23.1$, $df = 1,12$, $P = 0.001$), and was one of three sites with the most stems of balsam fir browsed ($F = 5.9$, $df = 1,12$, $P = 0.001$). However, two of five plots with significantly lower browsing on balsam fir compared to all other plots had significantly more deciduous stems than occurred on other plots. One of three plots with the highest levels of browsing on balsam fir had significantly less deciduous stems than we recorded for all other plots.

Results of analyses of damage to balsam fir by spacing were not entirely consistent between the two study areas. At Harpoon, significantly more stems were browsed, and were heavily damaged, at the 1.8 spacing than for the other three spacings (Table 7, Figures 3 and 4). Significantly fewer stems were heavily damaged at the 1.2 m spacing compared to the other spacings. Expressed as a proportion of stems browsed by spacing, a significantly lower proportion of stems were browsed at the 1.2 m spacing, while the proportion damaged was the same on the other spaced plots. At Jeffrey's, although the graphic trend was the same as for Harpoon, there were no significant differences in browsing on balsam fir among the four spacings. There was a significantly higher number of trees heavily damaged at Jeffrey's, on the fertilized plot compared to all other plots. ($F = 15.4$ $df = 1, 4$, $P < 0.01$). A significantly lower proportion of stems were damaged at the 1.2 m spacing compared to the other plots (Table 7) and two of three 1.2 m plots had the lowest proportion of stems damaged among all plots for all spacings. Even with relatively light browsing at Jeffrey's, more than 12% of the trees were heavily browsed on plots with a 3.0 spacing.

There were some among plot, within spacing differences determined by nested ANOVA. However, at Harpoon all of the 1.8 m spaced plots were among the most heavily browsed group of plots, and all of the 1.2 m plots were among those with significantly least damage. There was no trend among the plots for the other two spacings (2.4 and 3.0 m) (Tables 5 and 7). At Jeffrey's, we observed no

Table 4. Mean number of stems per 25m², standard deviation, and percent species composition, for three height classes on 4 spacings at Harpoon and Jeffrey's study sites. (N = 60 plots/space)

		Harpoon									Jeffrey's								
		<1 m			1-3 m			3 m			<1 m			1-3 m			3 m		
Space	Species	$\bar{x}$	SD	%	$\bar{x}$	SD	%	$\bar{x}$	SD	%	$\bar{x}$	SD	%	$\bar{x}$	SD	%	$\bar{x}$	SD	%
0 m*	Balsam fir	11.67	7.95	86.8	48.55	25.1	84.4	3.11	4.14	90.4	6.80	14.21	88.3	43.20	35.23	67.8	11.95	12.50	69.3
	White spruce	0		0	0.11	0.33	<1.0	0.11	0.33	12.8	0.05	0.22	<1.0	0		0	0.45	0.82	2.6
	Black spruce	0		0	2.33	2.78	4.0	0.22	0.44	6.4	0		0	0		0	0		0
	Deciduous*	1.78	1.39	13.2	6.55	4.21	11.4	0		0	0.85	1.69	11.0	20.50	14.65	32.2	4.85	6.23	28.1
1.2	Balsam fir	3.75	3.31	73.7	10.07	5.33	85.6	1.94	2.01	92.3	2.70	2.20	18.6	8.58	3.95	65.2	5.02	2.95	96.3
	White spruce	0		0	0.11	0.31	<1.0	0.05	0.37	2.4	0		0	0		0	0.12	0.37	2.3
	Black spruce	0.05	0.21	1.0	0.31	0.83	2.2	0.11	0.53	5.2	0					0	0.02	0.13	1.0
	Deciduous	1.29	2.25	25.3	1.27	1.86	8.7	0		0	11.78	12.19	81.3	5.30	6.67	34.7	0.05	0.22	1.0
1.8	Balsam fir	6.45	5.17	88.4	10.42	4.81	81.8	0.42	0.85	77.8	4.28	2.69	21.4	7.95	3.60	57.7	1.77	2.20	87.6
	White spruce	0.02	0.13	<1.0	0.13	0.34	1.0	0		0	0		0	0.02	0.13	<1.0	0.10	0.30	5.0
	Black spruce	0.02	0.13	<1.0	0.53	0.95	4.2	0.12	0.37	22.2	0.12	0.41	<1.0	0.15	0.40	1.1	0.15	0.36	7.4
	Deciduous	0.80	1.70	11.0	1.65	2.61	13.0	0		0	15.55	13.96	77.9	5.65	7.95	41.0	0		0
2.4	Balsam fir	3.98	3.04	79.6	5.15	3.14	82.8	1.57	0.87	96.9	3.58	4.00	19.0	5.75	4.21	27.1	2.02	1.51	93.9
	White spruce	0		0	0.07	0.25	1.1	0.02	0.13	1.2	0		0	0.03	0.16	<1.0	0.10	3.30	4.6
	Black spruce	0.07	0.31	1.4	0.40	2.77	6.4	0.03	0.18	1.8	0		0	0	0		0.03	0.16	1.4
	Deciduous	0.90	1.95	18.2	0.60	1.30	9.6	0		0	15.25	16.19	81.0	5.45	20.37	72.8	0		0
3.0	Balsam fir	5.55	4.21	79.9	4.40	2.81	73.0	0.94	1.14	88.7	4.91	3.54	26.2	4.46	2.28	39.7	1.00	1.11	97.0
	White spruce	0		0	0.08	0.37	1.3	0.03	0.17	2.8	0.01	0.11	<1.0	0.03	0.16	<1.0	0.01	0.11	1.0
	Black spruce	0		0	0.28	0.60	4.6	0.09	0.03	8.5	0.05	0.35	1.9	0		0	0.01	0.11	1.0
	Deciduous	1.40	2.89	20.1	1.27	2.21	21.1	0		0	13.77	12.51	73.5	6.75	7.65	60.0	0.01	0.11	1.0

* 0 spacing refers to unthinned plots.

* Deciduous was primarily white birch and pin cherry.

Table 5. Browsing rates on trees > 1 m tall for each spacing at the Harpoon and Jeffrey's sites. (Heavy = > 50% removal of annual growth or stem broken; Broken = stem broken; Total = all browsed stems; % = class expressed as a percentage of all stems for each plot.)

			Harpoon						Jeffrey's					
			1-3 m			> 3 m			1-3 m			> 3 m		
Space	Species	Class	$\bar{x}$	SD	%	$\bar{x}$	SD	%	$\bar{x}$	SD	%	$\bar{x}$	SD	%
0 m*	Balsam fir	Heavy	0		0	0		0	0.15	0.67	0.5	0		0
		Broken	0		0	0		0	0		0	0		0
		Total	1.78	3.07	5.3	0.22	0.67	2.0	1.30	2.36	4.4	0.20	0.52	0.1
	Deciduous*	Total	6.00	4.03	91.6	0		0	0.93	0.15	92.7	4.10	5.81	84.5
1.2	Balsam fir	Heavy	1.64	2.20	16.3	0.41	1.20	14.6	0.50	0.96	5.4	0.40	0.85	14.9
		Broken	1.11	1.71	11.0	0.06	0.30	2.1	0.10	0.30	1.1	0.02	0.13	0.3
		Total	4.23	3.32	42.0	0.86	1.39	30.7	1.78	2.26	19.4	1.12	1.65	19.3
	Deciduous	Total	1.18	1.51	92.9	0		0	3.72	5.51	70.1	0.05	0	100.0
1.8	Balsam fir	Heavy	4.38	3.69	43.8	0.03	0.18	2.0	0.65	0.95	8.3	0.12	0.45	3.3
		Broken	3.38	3.19	33.8	0		0	0.13	0.34	1.7	0		0
		Total	7.43	3.42	74.4	0.28	0.69	18.3	2.61	2.23	33.5	0.62	1.22	16.9
	Deciduous	Total	1.62	2.34	98.2	0		0	4.05	6.43	71.6	0		0
2.4	Balsam fir	Heavy	2.72	2.50	50.6	0.72	1.26	29.4	0.95	1.35	15.9	0.35	0.66	12.4
		Broken	1.78	1.94	33.1	0.17	0.52	6.9	0.20	0.51	3.3	0		0
		Total	4.03	2.89	75.0	1.32	1.53	53.9	2.55	2.61	42.7	1.02	1.21	36.3
	Deciduous	Total	0.58	1.29	96.7	0		0	3.32	4.17	61.1	0		0
3.0	Balsam fir	Heavy	2.48	2.14	51.6	0.57	0.90	29.3	0.58	0.89	12.6	0.10	0.30	6.0
		Broken	1.73	1.74	36.0	0.02	0.12	1.0	0.07	0.26	1.5	0		0
		Total	3.55	2.30	73.9	0.91	1.14	46.9	2.25	1.82	49.0	0.48	0.69	28.6
	Deciduous	Total	1.27	0	100.0	0		0	3.56	5.39	52.7	0.01	0	100.0

* 0 m refers to unthinned stands

* Deciduous was predominantly white birch and pin cherry.

Figure 3. Browsing by moose on 4 spacings and in unthinned stands of balsam fir at Harpoon Brook, central Newfoundland. (Prop. = proportion).

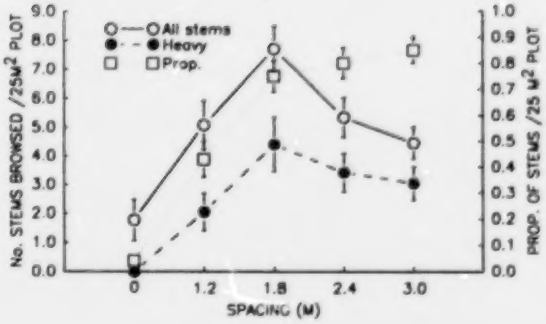

Figure 4. Browsing by moose on 4 spacings and in unthinned stands of balsam fir at Jeffrey's, western Newfoundland. (Prop. = proportion).

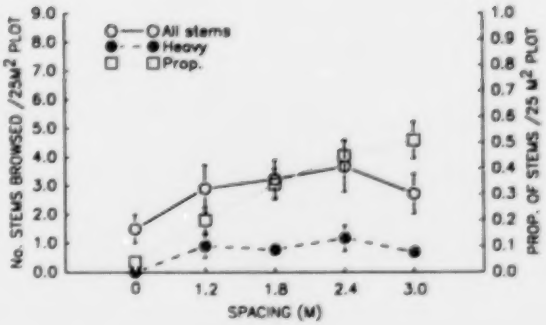

Table 6. Correlation analyses between the amount of browsing on balsam fir and the density of deciduous species available, and the amount of browsing on deciduous species, by spacing at the Harpoon and Jeffrey's sites. (N = 60 for each)

	Harpoon				Jeffrey's			
	Decid./m²		Decid. browsed		Decid./m²		Decid. browsed	
Spacing	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
0m	-0.06	0.87	0.10	0.88	0.39	0.09	0.30	0.23
1.2	-0.14	0.28	-0.10	0.38	0.11	0.38	0.07	0.54
1.8	-0.07	0.74	0.04	0.75	-0.16	0.21	-0.12	0.34
2.4	-0.25	0.05	-0.23	0.08	0.27	0.04	0.32	0.05
3.0	-0.33	0.01	-0.31	0.01	0.05	0.62	0.10	0.37

Table 7. Results of nested ANOVAs on amount of damage to balsam fir stems among and within spacings for two study areas at Harpoon Brook and Jeffrey's.

	Harpoon				Jeffrey's			
Dependent	Among		Within		Among		Within	
Variable	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Browsing on all stems	14.18	0.0001	1.82	0.07	1.40	0.23	9.78	0.0001
Heavy damage	7.62	0.0001	3.46	0.001	3.01	0.02	7.38	0.0001
Proportion of stems browsed	8.46	0.00001	1.59	0.13	4.85	0.0009	3.75	0.0004

consistency among the plots within spacings with regards to the number of stems damaged (Tables 5 and 7), suggesting that the few differences seen were influenced by differences among plots, more so than as a result of the spacing.

Results of stepwise multiple regression indicated that density of balsam fir on spaced plots was the only variable which affected the number of stems browsed. At Harpoon, the partial r^2 for density of balsam fir was 0.32, and at Jeffrey's it was 0.13. No other variable explained more than 5 percent of the variance at either site.

3) Physical and chemical characteristics of balsam fir twigs

Twigs from thinned balsam fir were longer, had larger diameters, and weighed more than twice as much as those from unthinned stands (Table 8). These values may be conservative as moose had removed some twigs from most of the thinned trees.

Twigs from trees in thinned stands contain a third more crude protein (N × 6.25), 17% more crude fat, 27% more phosphorus, 13% more calcium, and 20% more sodium than twigs from trees in unthinned stands. Potassium was the only nutrient in significantly greater concentration in trees from the unthinned stand compared to trees from the thinned stand.

Although twigs from thinned trees were statistically determined to be more digestible and contain less fiber (NDF or ADF) than those from unthinned trees, values for NDF and DMD were not substantially different for the two treatments (Table 8). DMD was significantly correlated with NDF ($r = -0.53$, $P = 0.0004$), ADF ($r = -0.53$, $P = 0.0005$), K ($r = 0.37$, $P = 0.02$), P ($r = 0.37$, $P = 0.02$), and N ($r = 0.38$, $P = 0.01$). However, regression analysis models using the latter five variables suggested that only NDF or ADF was important (Table 9). A minor improvement to the model was achieved using NDF and K. (K was correlated with ADF [$r = -0.55$, $P = 0.0005$], but not with NDF [$r = -0.25$, $P = 0.11$].)

Lavigne (1985) reported a current annual production of leaves four years after thinning of 1398 and

Table 8. Physical and chemical attributes of twigs of balsam fir from thinned and unthinned stands in central Newfoundland. (N = 40 for each treatment for all variables except ADF, NDF, and digestibility where N = 20, and for length and weights where N = 400.) Nutrient values and digestibility were measured using dry matter.

	Unthinned		Thinned		
Trait	$\bar{x}$	*SD*	$\bar{x}$	*SD*	*P*
Wet Weight (g)	1.57	0.60	4.04	1.47	0.0001
Dry Weight (g)	0.71	0.27	1.52	0.59	0.0001
Length (cm)	7.01	1.69	12.45	2.42	0.0001
Basal Diameter (mm)	2.17	0.52	2.71	0.41	0.0001
Crude protein (%)	5.94	0.75	8.29	1.50	0.0001
Crude fat (%)	10.64	0.61	12.43	0.71	0.001
Ash (%)	2.59	0.20	2.84	0.36	NS*
P (%)	0.11	0.02	0.14	0.02	0.001
Ca (ppm)	3141	1203	3570	932	0.03
K (ppm)	5443	630	4805	581	0.001
Mg (ppm)	420	142	385	115	NS
Na (ppm)	139	33	168	36	0.001
NDF (%)	44.28	1.70	42.91	1.66	0.05
ADF (%)	30.59	1.34	27.90	1.53	0.0001
Digestibility (%)	40.10	3.06	42.47	3.34	0.05

*NS = not significant, P 0.05)

Table 9. Significant regression equations for nutrient content variables correlated with dry matter digestibility from balsam fir twigs: neutral detergent fibre (NDF), acid detergent fibre (ADF), and potassium (K).

Equation	r^2	*P*	*SE*[a]
y = 85.02-1.00NDF	0.28	0.0004	2.90
y = 67.64-0.90ADF	0.28	0.0005	2.91
y = 73.23-0.88NDF + 0.001K	0.34[b]	0.0004	2.82

[a]SE = root mean square error.
[b]Partial r^2 for NDF = 0.284 and for K = 0.057.

2114 kg/ha in two thinned stands compared to 4679 and 4862 kg/ha in controls. Average leaf to twig weight ratios from our data were 1.6-2.2:1 for thinned stands, and 2.0-3.7:1 in unthinned stands. We therefore estimated total annual browse production in thinned and unthinned stands was 2682 ± 159 and 6539 ± 473 kg/ha, respectively.

We calculated that current annual growth of twigs plus foliage available was 0.26 ± 0.02 kg/tree in unthinned and 1.34 ± 0.08 kg/tree in thinned stands. Height in our unthinned stand and those of Lavigne were similar. However, Lavigne's thinned stands were two years older than our thinned stand, and averaged 5.7 m high. Our thinned stand averaged less than 4 m high, making the difference between the two production estimates conservative.

Seven secondary compounds made up approximately 96% of the volatile components from balsam fir leaves (Table 10). Limonene and ß-phellandrene were not separated by gas chromatography, but a subsequent gas chromatograph-mass spectrophotometric analysis separated the two compounds. Three compounds were significantly more concentrated in leaves from thinned compared to unthinned trees including camphene (+21%), ß-pinene (+20%), and bornylacetate (+21%).

Discussion

Damage to thinned stands

Damage to thinned balsam fir was greatest in the central portion of the province, particularly in the Noel Paul's Brook and Harpoon Brook drainage basins. Stands in the Cormack area were also heavily damaged, but most stands further south on the west coast were not severely browsed. Damage to many stands in central Newfoundland was sufficient to be of concern to forest managers. Precommercial thinning is a major component of silvicultural programs and costs about $600/ha. Moose have destroyed more than 30% of the trees in some stands putting the value of the damage in wasted management effort in the order of several hundred thousand dollars (based on the average of severe damage for all stands applied to the total area thinned in central Newfoundland). Further, our damage estimate is exclusive of the reduced commercial value of the remaining trees owing to reduced density of the stand.

The parallels between Newfoundland and Swedish moose herds and resultant problems for the forest industry are remarkable. Thinned stands of balsam fir present similar early successional habitat to moose as do plantations of Scots pine reported by Lavsund (1981). Damage levels found in this study were similar to those shown by Lavsund for northern Sweden.

Factors influencing level of damage

We observed that moose damage to balsam fir increased as a direct result of pre-commercial reduction of stand density, and with time spent by moose in the stand (or increased density of moose). No stand characteristics that we measured other than the percent of all shrubs that were balsam fir and density of balsam fir were important in influencing browsing on fir by moose. Deciduous shrub density was unimportant as a predictor of moose browsing on balsam fir from either the stand survey

Table 10. Concentrations (mg/ml) of plant secondary compounds in leaves of balsam fir from thinned and unthinned stands in central Newfoundland. ($N = 4$ twigs subsampled from each of 20 trees per treatment.)

Compound	Unthinned		Thinned		
	$\bar{x}$	SD	$\bar{x}$	SD	P
α-pinene	0.09	0.03	0.10	0.02	NS*
ß-pinene	0.37	0.13	0.47	0.19	0.03
Camphene	0.08	0.03	0.10	0.02	0.03
Limonene/ß-phellandrene*	0.11	0.04	0.14	0.05	NS
Maltol	0.79	0.17	0.78	0.24	NS
Bornylacetate	0.21	0.07	0.25	0.05	0.02

*NS = not significant ($P > 0.05$).
*Compounds not separated by gas chromotgraphy.

study, or the assessment of browsing at the spacing trials. The role of deciduous browsing and consequent browsing on conifers has also been examined in Scandinavia. Lavsund (1987) reported that the evidence was ambivalent with a positive relationship between deciduous browsing and browsing on Scots pine for some areas, and no relationship in other studies.

White birch was the most abundant deciduous species in all stands which we studied. Balsam fir in thinned stands contains significantly more protein than we found in birch [7.3% ($SD = 0.76$)] samples from the Southwest Gander River area (Thompson, unpub. data). Higher protein content in balsam fir twigs may explain the lack of a relationship between the density of deciduous vegetation and damage to balsam fir.

We believe that the presence of uncut forest as residual within the stand may also affect damage by making stands more attractive to moose, but we conducted no quantitative measurements during the stand surveys. Our data from the spacing trials do not support the contention that proximity to edge affects browsing rate. Lavsund (1987) reported that smaller areas were more heavily used than large clearcuts. Hamilton *et al.* (1980) and Thompson and Vukelich (1981) found that distance to edge was important in feeding but that distance moved out into an open area was affected by snow depth. The possibility of edge effect exists but requires further study.

Spacing between trees may influence moose damage to a stand, but our evidence was not conclusive. It is a reasonable assumption that because food quality is enhanced by thinning (see below), there exists a relationship between food quality and increased spacing, at least to some unknown asymptote occurred at a spacing greater than 1.2 m. Further, there was consistently least browsing on all of the 1.2 m plots. The Jeffrey's data, although suggestive of a similar trend, were not supportive as browsing occurred at equal rates for all spacings and differed among plots within spacings. Damage was most likely low at Jeffrey's because the moose population was lower there than at Harpoon. With a reduced density, moose should be more selective in their choice of browse because more food is available to individuals than at higher population density. A diet that includes a mixture of several browse species, where available, may be preferable to moose and the animals are likely also constantly sampling available forage (Robbins 1983). Moose at Jeffrey's may have been responding to the available mix of browse species and selected feeding areas on that basis rather than solely on the amount of fir present. Therefore the Jeffrey's data may not present a valid test of the spacing hypothesis, and we remain uncertain as to whether the Harpoon results were general or idiosyncratic.

Despite a greater total biomass of current annual growth in unthinned stands of balsam fir, moose preferred to browse in thinned stands. A lower biomass per unit area suggests that a greater effort per unit of food may be expended by moose feeding in thinned stands as compared to foraging effort needed in unthinned stands. Balsam fir trees in unthinned stands, stressed as a result of competition, do not grow as well as those spaced more widely

apart and Piene (1981) reported height growth increased by an average of 33% in stands with 6-10,000 stems/ha, compared to stands with 40,000 stems/ha. There is a linearly increasing relationship between height and amount of browse produced by individual balsam fir trees in Newfoundland (Parker and Morton 1978). It is probable that the higher protein content of twigs from thinned stands compared to unthinned stands was primarily responsible for moose choosing to feed in thinned stands. Secondly, the greater biomass available per tree and larger twig size (bite size) in thinned stands compared to in unthinned stands may also influence stand choice. These latter factors proabably more than offset extra energy required to move between trees in thinned stands. Danell *et al.* (1985) have also suggested that maximizing bite size was an important factor in browse selection in birches (*Betula* spp.).

Schwartz *et al.* (1987) reported that moose require approximately 6.8% protein on a dry weight basis in their diet as a minimum requirement for maintenance. Balsam fir twigs from the unthinned stand were on average (5.9%) below that level, while twigs from trees in the thinned stand averaged (8.3%) more than 19% above the minimum protein requirement.

A central question to our suggestion that moose elected to browse twigs with high protein levels is whether the animals can distinguish between good and poor forage. Evidence exists to suggest that herbivores do select foods of high quality when possible (Klein 1970; Owen-Smith 1982), and moose are well known to exhibit browse species preferences (Peek 1974). There have been no tests for selection by moose of a specific nutrient except sodium (Fraser and Reardor 1980) and no selection experiments have been conducted for varying levels of protein. Bergerud and Manuel (1968) suggested that moose avoided browsing on more chlorotic trees which had low protein levels. Loyttyniemi (1981) showed that there was greater browsing damage by moose in fertilized stands of Scots pine where the N content of leaves was higher than in unfertilized control stands. Our data from Jeffrey's also supports the observation that fertilization of forests will enhance damage by moose to shrub and tree species, including balsam fir.

Comparisons between our data and other browse species indicate that balsam fir is a highly digestible food (Oldemeyer *et al.* 1977; Regelin *et al.* 1987). Although digestibility was highest in twigs from thinned stands, there was sufficient variability to permit moose to choose plants with high digestibility in either type of stand. Further, regression analysis suggested that either NDF or ADF alone explained less than 30% of the variance in digestibility. Therefore, we do not believe that carbohydrate energy was an important factor in choice of stand type for browsing.

Observed differences in concentrations of macroelements between trees from thinned and unthinned stands may also have influenced moose to feed in thinned stands. Levels of Na, Ca, and P were all highest in thinned stands. There are few published data to suggest whether the levels which we determined for balsam fir were adequate as a sole source of macroelements. Belovsky and Jordan (1981) suggested that moose require 90-200 ppm Na in their diet. Our data showed that balsam fir contained a sufficient amount of Na to meet this requirement in both types of stands, although Na levels were 20% greater in thinned trees. Phosphorus levels of 0.1% were described as "very low" by Kubota *et al.* (1970), and Church (1971) found that levels for cattle should be 0.25-0.35%. Although thinned trees contained more P than unthinned trees, values were probably below daily requirements for moose. The other macroelement in significantly higher concentration in thinned trees was Ca. Robbins (1983) indicated that white-tailed deer *(Odocoileus virginianus)* require 0.4-0.64% Ca in the dry diet. Our values for balsam fir are slightly below that level. We conclude that thinned trees are probably not selected by moose to fulfill a need for a specific macroelement, although if the animals were deficient in Ca or P use of thinned over unthinned stands would be preferable.

Trees from our thinned stand had higher levels of crude fat (which contain resins and some monoterpenes) than did trees from the unthinned stand. This is opposite to the prediction from Coley *et al.* (1980) that the faster growing plants should contain fewer defensive chemicals. Differences in other secondary compound concentrations were statistically different but small. Clearly the higher levels of secondary compounds had no strong influence on digestion or feeding preference would have been indiscriminate or opposite to that observed by Thompson (1988),

that is greater use of unthinned stands.

A general tendency toward lower digestibility as a function of increasing twig size has been reported for deciduous twigs (Hjeljord *et al.* 1982; Bergstrom and Danell 1986; Vivas and Saether 1987), reflecting increased lignin and cellulose content of the woody fiber. We observed no marked trend for digestibility of balsam fir between the small twigs from unthinned stands and the larger diameter twigs of thinned stands. This result may suggest that a secondary compound which we did not analyze, such as tannins, may have occurred in higher concentrations in twigs from unthinned trees than in thinned trees. Therefore, while our data generally do not support the plant defence theory, neither can we totally reject it.

We conclude that moose browsed trees in thinned stands preferentially over those from unthinned stands because of the greater biomass of superior food available per tree in the former stand type. In particular, we suggest that because protein levels available in unthinned stands were below daily requirements, that given a choice moose would browse trees in thinned stands of balsam fir.

Management Recommendations

We propose management recommendations for two aspects of the problem of moose browsing through suggestions for commercial thinning methods, and recommendations for integrated management of the forest in areas where moose may seriously damage second forest growth.

Guidelines for thinning operations

Thinning of stands could be conducted so that stands are somewhat less attractive to moose, using the following guidelines: 1) straightening all edges of thinned stands in order to reduce total edge of a stand, 2) removal of all unmerchantable standing timber while harvesting stands that are expected to regenerate to balsam fir, 3) reducing the density of fir under 3 m tall by delaying thinning operations in areas of known high moose density until the average height of dominant trees is a minimum of 4.0 m (most stems that were broken we estimated were approximately 3.0-3.5 m tall; trees taller than 4.5 m were rarely broken). Data from Lundrigan (1989) suggest that an average balsam fir height of 4 m in an unthinned stand will occur at about 11-12 years after logging.

4) The spacing trial study suggested that a spacing distance of 1.2 m may reduce damage to the stand in an area of heavy browsing. That is, leaving more fir will reduce the proportion of stems taken from the stand by moose. Managers should consider a trade-off between stand growth rate at a higher than optimum tree density, and browsing damage that will occur to an optimally spaced stand during the period before all trees are sufficiently tall to escape damage. Although stem growth will not be maximized in a denser than optimal stand, moose browsing will reduce the stand density over several years: e.g., from an initial density of 6000 stems/ha, browsing will reduce the stem density to about 3700 stems/ha after three years, assuming heavy browsing damage of 15% a year, as seen at Harpoon for 1.2 m spacing (assuming a moose population comparable to that in the Noel Paul area). Also, moose will generally leave the taller trees and browse those less than 3 m. It may be possible to use moose to at least some extent to act as thinning agents.

Guidelines for resource management

Damage to stands was primarily a function of the amount of time moose spent in thinned stands. Equal "time" in a stand can result, for example, from one moose spending 10 days, or 10 moose spending one day in the stand. Regardless, our data suggest the probability of damage to a thinned stand increases with population density. In Norway, Skogsstyrelsen (1983, cited in Lavsund 1987) reported that a moose density of 1.0/km^2 would result in 10% severely damaged stems, and 2.0 moose/km^2 would produce 25% severe damage. Bergerud *et al.* (1968) showed that a population reduction resulted in less damage to balsam fir in the Noel Paul area in 1961-64. Sweden currently has a management objective to reduce moose populations through hunting in areas where timber is the primary resource.

We recommend that management decisions be made before thinning operations are carried out as to whether an area is to be managed for timber or moose as the priority resource, given that other resource values are being met elsewhere. Assuming under an integrated resource plan that the featured value from a given block of land has timber as a priority with moose as a secondary resource, then clearly to maintain maximum timber production moose density would have to be lower than that found presently in the central portion of Newfoundland. Further, a low density of moose would necessarily have to be maintained until the stand had

grown sufficiently to be immune to severe browsing damage. That time period is about 6 years on a good site to allow 90% of the trees to attain a height of 5 m, for a stand thinned at an average height of 3 m, using growth rate data from M.B. Lavigne (unpub. data) of 0.3 m/yr.

Our data showed that damage was a linear function of moose density at high moose density. Therefore a reduction in damage by moose to a thinned stand can be achieved by reducing moose density. As an example for the Noel Paul/Harpoon area, we determined that average heavy damage to thinned stands was 14 percent. Therefore, if an acceptable level of heavy damage is say 5 percent of a stand per year over three years, then moose density in the Noel Paul/Harpoon area should be reduced by approximately two-thirds, to a density of 1 or less/km^2.

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